

Impact of Water Stress on the Planktonic Biodiversity of the Youssef Ben Tachafine Dam (Souss Massa, Morocco)

Fatima Boudarfa^{1*}, El Mahjoub Gallouli¹, Mohamed El Hafa¹,
Ahmed Aamiri¹, Hassan Oulad Ali¹

¹ Biodiversity and Ecosystem Functioning Team, Faculty of Sciences of Agadir, Morocco

* Corresponding author's e-mail: f.boudarfa@gmail.com

ABSTRACT

Drought is a large-scale disturbance that affects freshwater ecosystems worldwide. This recurrent phenomenon in Morocco, has experienced severe episodes during the last decade and has caused water stress in several aquatic ecosystems including the Youssef Ben Tachafine dam. Indeed, the volume of this reservoir has experienced its lowest historical hydrological level (12%) during the study period. To study the effects of water stress on water quality and planktonic community structure, water samples were collected from January 2019 to December 2020 at nine depths. The physicochemical parameters of the water were measured in parallel with the qualitative and quantitative study of the phytoplankton and zooplankton communities. The results obtained show a low planktonic diversity with only 43 phytoplanktonic species and 27 zooplanktonic species. The phytoplankton showed an almost permanent predominance of Chlorophyceae (85%), dominated by *Closterium pronum*, followed by Diatomophyceae (9.5%), dominated by *Cyclotella ocellata*. Rotifers represent the most abundant zooplanktonic group during the study period with two dominant species (*Keratella tecta* and *Polyarthra vulgaris*). Statistical analysis of the data from this study, using R software, revealed a negative correlation between Cladoceran species, Copepods and the diatom *Cyclotella ocellata* on the one hand and the decrease in water level, temperature and enrichment of the environment in nutrients and phytoplanktonic biomass on the other. This study shows that the effect of the extreme drought, which the Youssef Ben Tachafine dam has experienced, has altered the diversity and structure of planktonic communities, which threatens the sustainability of ecological services of this ecosystem.

Keywords: biodiversity, Youssef Ben Tachafine dam, zooplankton, phytoplankton, drought.

INTRODUCTION

In arid and semi-arid regions, dam reservoirs represent the main source of drinking water supply (Erol and Randhir 2012). These reservoirs are faced with very severe changes in water levels, due to frequent droughts and short periods of precipitation. The drop in water level during droughts can lead to major changes in the structure and composition of the lake ecosystem in general and the planktonic community in particular (da Costa et al. 2016). The latter plays a crucial role in the transfer of energy to the higher trophic level. Phytoplankton plays an important role in the primary production of freshwater and is the main food for zooplankton, and fish (Mishra 2017). Phytoplankton biomass and species composition influence

the ecological status of an area. Some of these species are good indicators of ecological status (low or high) (Borja 2005). Zooplankton have an influence on the structure of the phytoplankton community because of their grazing pressure and excretions. The latter increase the concentration of nutrients in the water mass which leads to the proliferation of phytoplankton which has a negative impact on the uses of water resources. The reduction of the water level of dam reservoirs modifies the physicochemical characteristics of the water, which affects the biomass and structure of planktonic communities by favoring phytoplankton species less demanding in nutrients (de Castro Medeiros et al. 2015), and small zooplankton species (Neelgund and Kadadevaru 2021; Gannon & Stemberger 1978).

Among the aquatic ecosystems of Morocco, the Youssef Ben Tachafine dam, installed on Oued Massa, forms with its estuary one of the hydro-systems most affected by the recurrent droughts that southern Morocco has experienced. This reservoir represents the main source of drinking water and irrigation for local communities. The understanding of the influence of low water inputs on the physicochemical quality and planktonic biodiversity of the environment is of paramount importance for the management practices of surface aquatic ecosystems. This work aims to identify and understand the impact of drought on the intensity of erosion of planktonic biodiversity in the dam Youssef Ben Tachafine.

MATERIALS AND METHODS

Characteristics of the study environment

The Youssef Ben Tachafine dam (southern Morocco) is located 90 km south of the city of Agadir, and 30 km north of the city of Tiznit, its Lambert coordinates are as follows: X = 104.4; Y = 323.40 (Figure 1). This reservoir was put in water at the end of 1972 and ensures the regulation of a volume of 90 Mm³ of water, of which 85 Mm³ of this volume are transferred for irrigation, while 5 Mm³ are intended to supply the cities of Tiznit and Sidi Ifni with drinking water. In addition to these two objectives, the dam ensures the protection of the downstream against flooding.

Sampling

The sampling for the study of planktonic population, and physicochemical parameters is carried out at a single sampling station chosen according to its depth. The sampling lasted two years, from January 2019 to December 2020, with a monthly step in winter and spring and bimonthly in summer and fall. Water samples for physicochemical and quantitative plankton analyses were taken using a horizontal WILDKO bottle with a capacity of 2 liters at different depths: surface; 1 m; 2.5 m; 5 m; 7.5 m; 10 m; 12.5 m; 15 m; and 20 m. At the end of the sampling period, when the reservoir is at these shallow depths, only the water column at 16 m depth is surveyed. For the qualitative study of plankton, the samples were taken by vertical and horizontal lines using a plankton net of 20 µm mesh size.

Analysis methods

Temperature, conductivity and dissolved oxygen were measured in situ using a multi-parameter instrument (HI 98196 brand HANNA). Transparency was measured in meters using a Secchi disk immersed in the sampling station. Unwanted substances (iron, manganese and hydrogen sulfide) were determined by a colorimetric method using the analysis kits. The plankton samples were immediately fixed on site by adding 4% formaldehyde.

In the laboratory, the unfixed samples intended for the determination of the species were first analyzed on the same day of collection after

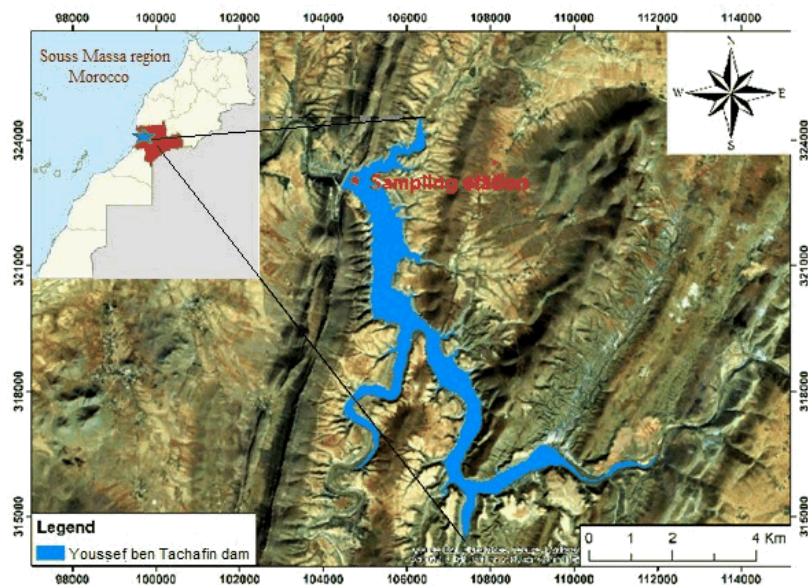


Figure 1. Schematic representation of the Youssef Ben Tachafine dam

a few hours of deposition using an optical microscope (type OPTECH B3). The identification of phytoplanktonic species was made on the basis of determination keys and the work of Bourrelly (Bourrelly 1966, Bourrelly 1970). Cell counts were performed on formalin-fixed samples using the classical Utermohl (Utermohl 1958) using an inverted microscope (type OLYMPUS). The determination of the zooplanktonic species was made using the determination keys (Dussart 1969, Amoros 1984). The enumeration of these species was done in a Dolfus tank under a binocular loupe.

Total phosphorus, nitrate, ammonium and silica were analyzed using an atomic absorption spectrophotometer according to the water analysis protocol (Afnor 1994, Rodier 1994). The chlorophyll-a pigments were extracted in 30 ml of hot ethanol and the determination was performed according to the Lorenzen method (Lorenzen 1967). Suspended solids were measured by differential weighing of Whatman 0.45 μm filters before and after filtration of the sample and drying in an oven at 105°C (Rodier 1994).

Statistical analysis

Phytoplankton and zooplankton abundance, species density, Shannon diversity index (H' , bits), and evenness were used as univariate descriptors to assess the structure of these two communities. Abiotic variables were correlated with the main phytoplankton and zooplankton species using Spearman's nonparametric coefficient. The spatio-temporal analysis was then analyzed using a standardized principal component analysis (PCA) to determine the influence of physico-chemical parameters between them and on the most abundant species in the waters of the Youssef Ben Tachafine dam. These tests and analysis were performed using the software R version Rx64 4.0.2 with the package Rcmdr and the plug-in Facto Miner. While the graphs were made using software PAST.

RESULTS

Physicochemical parameters

Significant variations in water temperature in the YBT reservoir have been recorded from season to season, with a maximum of 27.3 °C recorded in the surface waters in August of 2019–2020 and a minimum of 15.80 °C recorded in February 2019 in the bottom waters. Thermal stratification begins in late March and continues until early October generating a decreasing thermal gradient

with depth. Conductivity was well marked by its increase with time and by its homogenization over the whole water column. However, the variation of dissolved oxygen showed a separation between the well oxygenated surface layers and the deep anoxic layers during the period between April and November of each year. Dissolved oxygen levels recorded during this study range from 0 mg/L at the bottom to 9.28 mg/L at the surface. In addition, chemicals such as manganese, hydrogen sulfide, and iron were recorded during thermal stratification and deep-water anoxia. The concentration of nitrates recorded in summer was very low, this would be related to the thermal stratification of the water column that took place during this period. While the highest levels were recorded in winter 2019 and late fall 2020 (Figure 2a).

Ammonium concentration varies from year to year and season to season with higher levels recorded in summer in the hypolimnion (Figure 2b).

Total phosphorus levels showed significant fluctuations across the water column, ranging from 0.00 mg/l to 0.28 mg/m³. Low phosphorus values were recorded at the surface in summer 2019 and late fall 2020, while high concentrations were recorded at the deep layer levels in summer during both sampling trips (Figure 2c). As for silica's, an increasing concentration gradient developed between the surface and the bottom of the YBT reservoir (Figure 2d).

Biological parameters

Chlorophyll-a

Chlorophyll-a concentration showed an irregular spatiotemporal distribution with a net decreasing gradient from the surface to the bottom of the reservoir, with high concentrations at the top ten meters and zero values at the deep layers. Its seasonal evolution showed heterogeneity from year to year with two peaks in 2019, the first in early spring (9.9 mg/m³) and the second in early autumn (10.5 mg/m³). While in 2020, a single peak (19.60 mg/m³) was recorded in August (Figure 3).

Plankton diversity indices

The diversity indices of the phytoplankton community are shown in Figure 4 (a), the highest diversity ($H' = 2.26$, $J' = 0.79$) was observed in January 2019 and the lowest value ($H' = 0.06$, $J' = 0.02$) was detected in August 2020. The Shannon index correlated negatively with Chlorophyceae ($r = -0.78$, $p < 0.001$) and Diatomophyceae

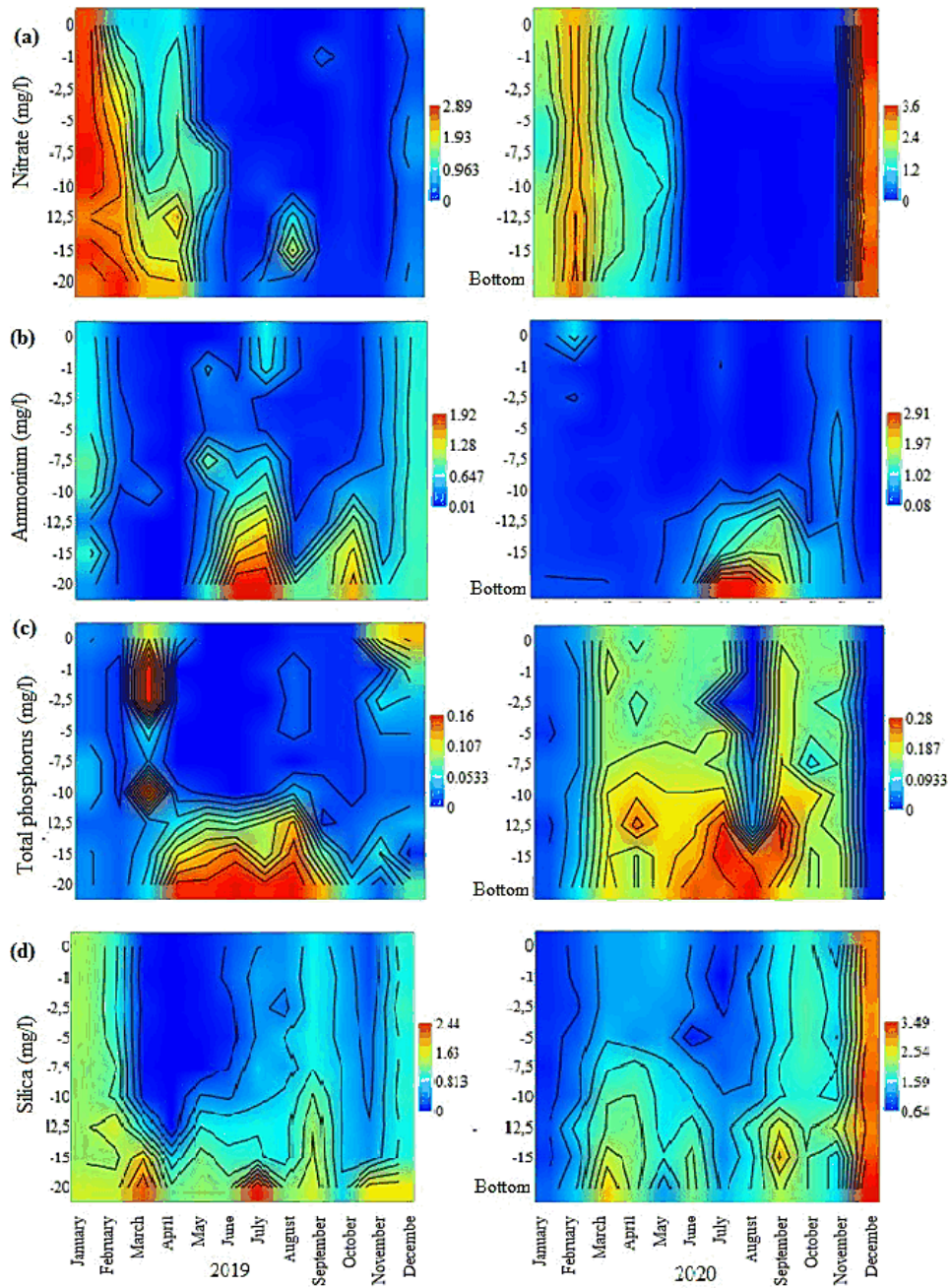


Figure 2. Spatiotemporal variation of (a) nitrates, (b) ammonium, (c) total phosphorus and (d) silica at Youssef Ben Tachafine dam during the study period

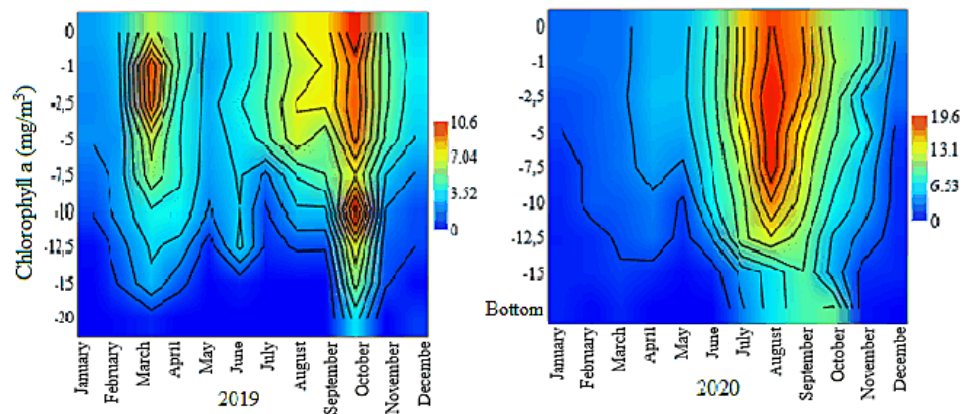


Figure 3. Spatiotemporal variation of chlorophyll-a at Youssef Ben Tachafine dam during the study period

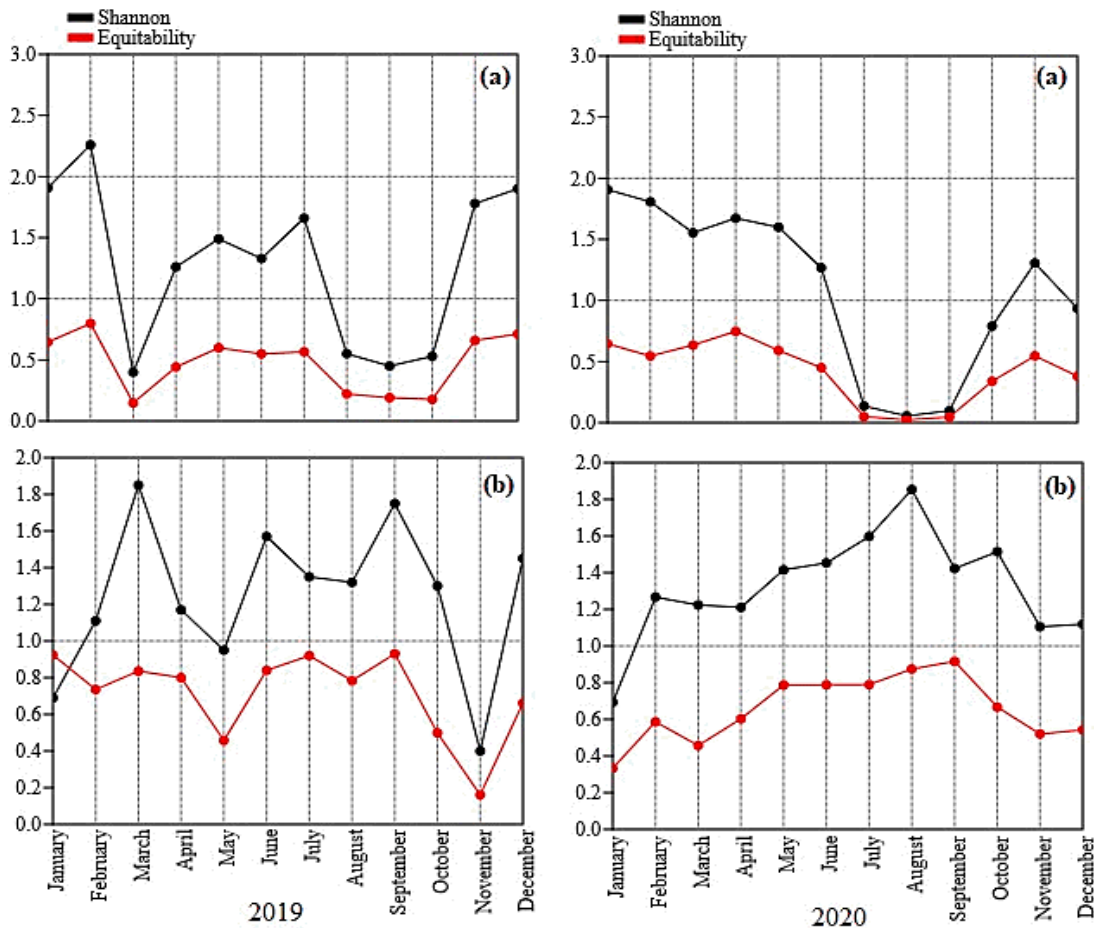


Figure 4. Representation of Shannon index and equitability of phytoplankton (a) and zooplankton (b) in Youssef Ben Tachafin dam

($r = -0.44$, $p < 0.01$) and positively with Dinophyceae ($r = 0.63$, $p < 0.001$), Cyanophyceae ($r = 0.66$, $p < 0.001$) and Zygnematophyceae ($r = 0.47$, $p < 0.01$).

L'indice de Shannon de la communauté zooplanctonique de la retenue YBT varie entre 0.40 et 1.85 bits (Figure 4b). La faible valeur de cet indice a été enregistrée en novembre 2019 qui a connu une forte abondance de l'espèce *keratella tecta*. The Pielou equitability index ranged from 0.16 to 0.93. The highest values of this index were recorded at the surface layers and the lowest values were recorded in the deep waters of the reservoir.

Composition and abundance of phytoplankton

This study has highlighted a low specific richness of the phytoplankton community of the Youssef Ben Tachafine dam. Indeed, only 43 taxa have been identified including 14 Chlorophyceae, 11 Diatomophyceae, 6 Cyanophyceae, 4 Euglenophyceae, 4 Zygnematophyceae, 3 Dinophyceae and one Cryptophyceae species. The Chlorophyceae class is dominated by the species *Closterium*

prorum, which constitutes an important part of the phytoplanktonic density of this reservoir. Within Diatoms, the genus *Cyclotella* was identified in the waters of the YBT Dam impoundment only in 2019 and at high abundance.

Phytoplankton cell densities were highest at the surface and lowest at the bottom of the YBT reservoir (Figure 5a). The year 2019 was characterized by the abundance of three phytoplankton species *Cyclotella ocellata*, *Closterium prorum*, and *Nitzschia acicularis*. While the year 2020 was characterized by the dominance of Chlorophyceae (Figure 5b) mainly the species *Closterium prorum* (Figure 5c).

Composition and abundance of zooplankton

Analysis of the zooplankton community in the YBT reservoir revealed the presence of 27 species including 15 Rotifers, 7 Cladocerans, 2 Copepods, and 2 Oligotriches. The frequency of occurrence of these species during this study differed from year to year and from season to season.

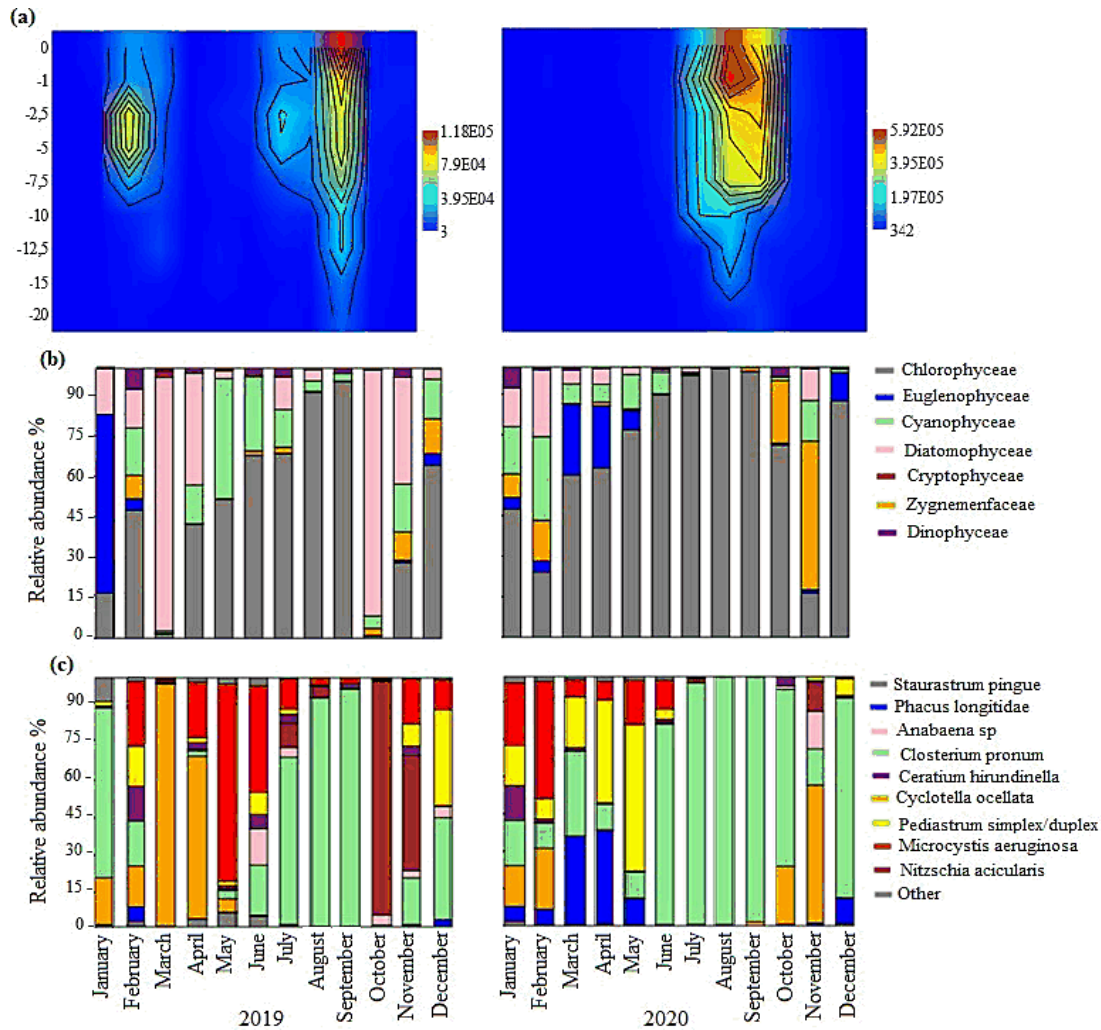


Figure 5. Spatial and temporal variation of total phytoplankton density (a), Relative abundance of seven classes of phytoplankton (b), evolution of phytoplankton species (c) in Youssef Ben Tachafin dam

Zooplankton densities recorded during the two study cycles were comparable between years. The highest densities were recorded at depth 2.5 m in November 2019 ($2.60 \cdot 10^3$ ind/l) and January 2020 ($2.11 \cdot 10^3$ ind/l). While low densities were recorded during summer periods (Figure 6a).

In terms of abundance, Rotifers were the most abundant zooplankton group, followed by Tintinnids which showed very low abundance in 2019 and high abundance in 2020 with maximum abundance recorded in August 2020. The abundance of these two groups accounted for 68% of the total zooplankton abundance (Figure 6b). While Copepods and Cladocerans were less abundant during the study period with a relative abundance not exceeding 3.5% (Figure 6b). *Keratella tropica*, *Keratella cochlearis*, *Keratella tecta*, *Asplanchna priodonta*, *Polyarthra vulgaris* and *Tetramastix opoliensis*, are the six Rotifer species that recorded a

significant frequency of occurrence compared to the other Rotifers (Figure 7a).

The Cladoceran class in YBT Dam impoundment was more diverse in 2019 than in 2020 and the relative abundance of different Cladoceran species also differed between years. In 2019, the species *Diaphanosoma brachyurum* accounted for 45% of the total Cladoceran density, followed by *Daphnia magna* (29%) and in 2020, the relative abundances of these two species were 21% and 73% respectively. The highest density of Cladocerans was recorded in winter 2020, following the development of *Daphnia magna* (Figure 7b).

Copepods were represented by only two species during the study period:

- *Thermocyclops dybowskii*: a dominant Cyclopoid in the waters of the YBT Dam impoundment with a relative abundance of 90% in 2019 and 97% in 2020.

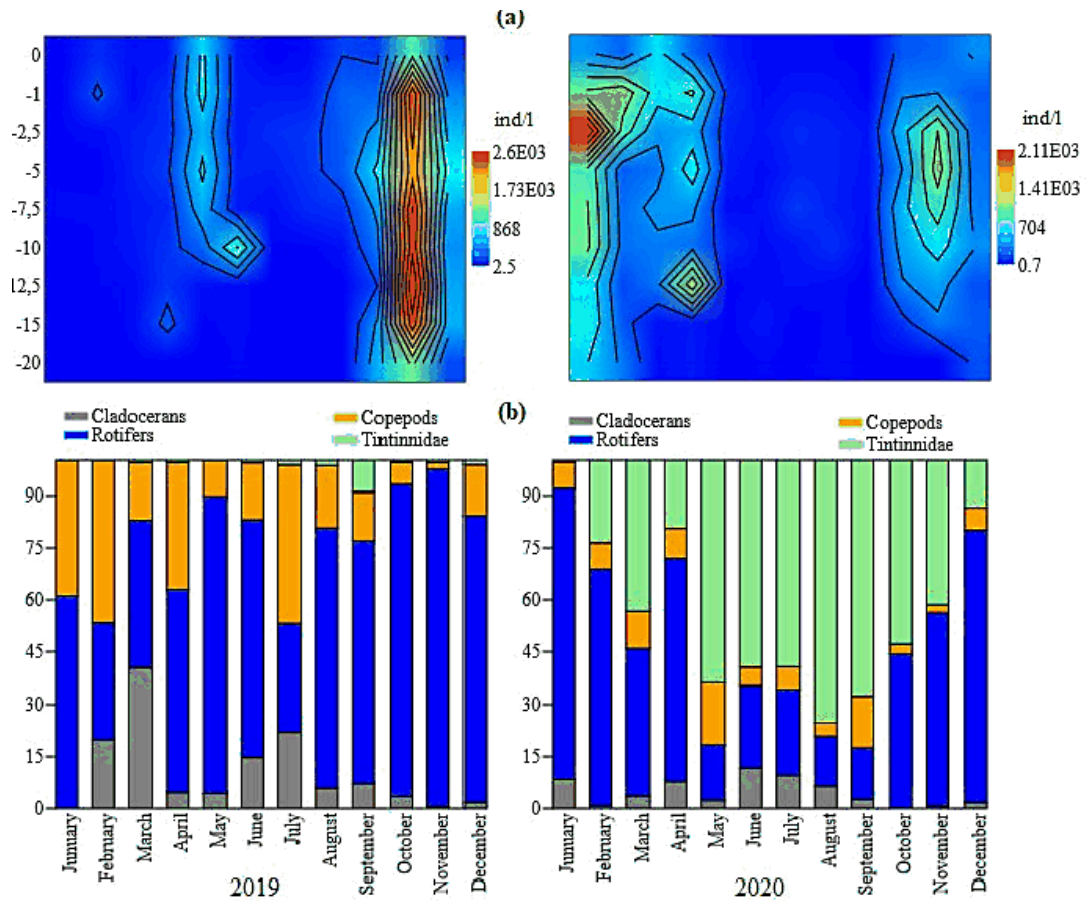


Figure 6. Spatial temporal evolution of the total density of zooplankton (a) and temporal evolution of the relative abundance of zooplankton classes (b) in the Youssef Ben Tachafine dam

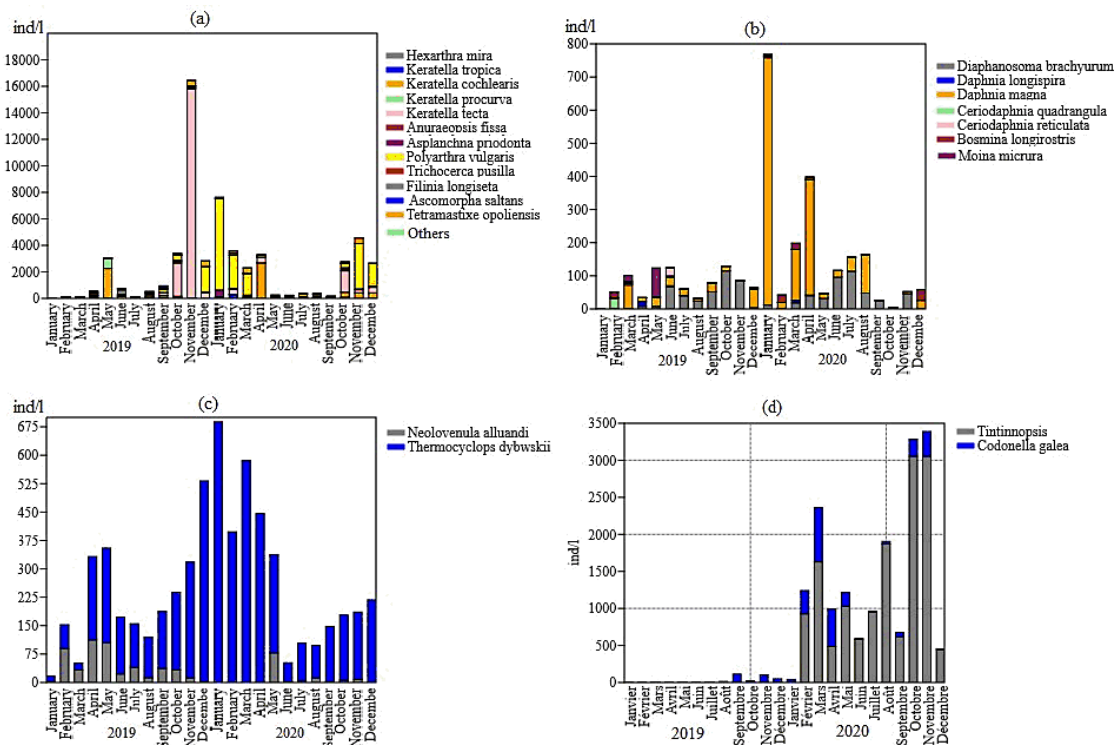


Figure 7. Temporal evolution of the total density of Rotifer species (a), Cladoceran species (b), Copepod species (c) and Tintinnidea species (d) in the Youssef Ben Tachafine dam

- *Neolovenula alluandi*: a Calanoid with a relative abundance of 19% in 2019 and 3% in 2020 (Figure 7c).

The Tintinnidae stand was represented by the species *Codonella galea* and *Tintinnopsis sp.* The latter showed high densities in October and November 2020 with 3268 ind/l and 3388 ind/l respectively (Figure 7d).

Physicochemical and planktonic typology of the YBT dam reservoir

Standardized principal component analysis (PCA) was used to visualize the relationship between the different components of the planktonic community in the YBT dam impoundment and the influence of the physicochemical parameters of the environment on these components. The first factorial design (F1·F2) of this PCA represents 94% of the total variance (Figure 8a). Copepods and Cladocerans showed a strong correlation with the diatom *Cyclotella ocellata* which exhibited high abundance in winter when the waters of the YBT dam impoundment are well oxygenated, nitrate rich, unstratified. In contrast, no zooplanktonic species were correlated with the chlorophyte *Closterium prorum*, which exhibited high abundance in summer when manganese concentration, water temperature and conductivity were high.

Rotifers and Tintinnids correlated strongly with the diatom *Nitzschia acicularis*, whose abundance was high in autumn when the reservoir waters were rich in silica.

The results of the projection of individuals (seasons) onto the F1·F2 factorial plane (Figure 8b) show that hydrology, temperature, conductivity, nitrate, dissolved oxygen and ionic chemical elements varied seasonally which may be behind the seasonal variation in plankton composition, as well as the succession and abundance of its phytoplanktonic and zooplanktonic species in the YBT dam reservoir.

DISCUSSION

The phytoplankton community of the YBT dam reservoir is not very diverse compared to other Moroccan reservoirs (Gartet et al. 2009, Benhayoune et al. 2017, Belokda et al. 2019). The vast majority of species belong to the Chlorophyceae family, followed by the Diatomophyceae and Cyanophyceae. These species generally tolerate important thermal variations, which explains their high abundance, this situation is similar to that recorded in various eutrophic artificial lakes (Samoudi et al. 2016, Öterler et al. 2018, Varol 2019, Liu et al. 2021). The differentiation between these three classes and the other classes of phytoplankton is closely related to the availability of preferred physicochemical conditions in the water column. This further explains the difference in significant correlations between the dominant species and the environmental variables identified by PCA. The diatom *Cyclotella ocellata* proliferated in winter. This proliferation would be linked to a high concentration of nitrates and an optimal water temperature close to 20 °C, and its marked decline in

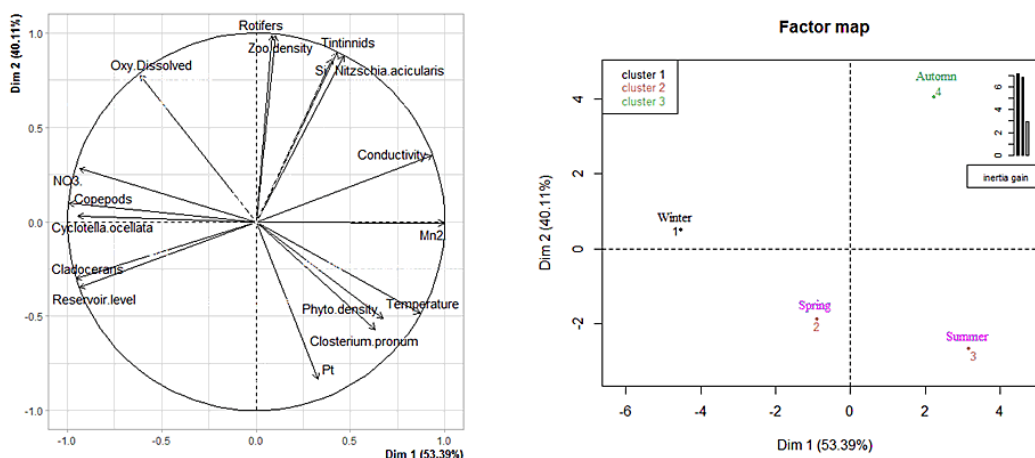


Figure 8. Correlation circle of environmental variables and the main dominant planktonic species of YBT dam (a), projection of individuals (seasons) on the first two dimensions of the PCA. Mn²⁺: manganese, Pt: total phosphorus, Si: silica and NO₃⁻: nitrate

spring coincides with thermal stratification and low nitrate concentration. It appears that the abundance of this diatom is strongly affected by intense sunlight and thermal stratification (Fadel et al. 2015) or by its selective grazing by zooplankton.

In general, nutrient availability is the main factor controlling Chlorophyceae in eutrophic lakes when temperature and light conditions are favorable (Chikhaoui et al. 2008). The development of *Closterium pronum* has a direct and visible effect on the transparency of the water (it is 0.8 m in August 2019 and 0.7 m in August 2020) and on the organoleptic quality of the water (unpleasant color and smell). The reduction in water transparency of the Youssef Ben Tachafine reservoir was also associated with the resuspension of sediments during water mixing in early winter (0.3 m), which leads to the conclusion that transparency is a key factor, affects the structure of the phytoplankton community of the YBT dam reservoir. The proliferation of large elongated unicellular phytoplankton cells such as *Closterium pronum* and the appearance of filaments of *Mougeotia* sp, *Spirogira* sp and the Cyanobacterium *Raphidiopsis raciborski* in summer, confirm the hypereutrophic state of this reservoir. These observations also correspond to the results of numerous studies on shallow and eutrophic lakes (Naselli-Flores and Barone 2000, Zębek and Szymańska 2017). It should be noted that the bloom of the species *Closterium pronum* is specific to the Youssef Ben Tachafine dam, according to previous studies, it has never been detected in bloom at the level of other Moroccan dams (Benhayoune et al. 2017, Belokda et al. 2019). This species has proven to be more tolerant of the nature of nutrients from sediment release during thermal stratification and the dry climatic conditions of the region, and could become a nuisance due to its considerable density. However, the decrease in water level resulted in the dominance of a single species capable of adapting to the stressors and thus a decrease in phytoplankton diversity. In addition, the Shannon-Wiener index values of the phytoplankton community, of the YBT dam impoundment, classified it as a stressed and disturbed ecosystem. In addition, the low uniformity index values confirm that the distribution of phytoplankton in this impoundment is inequitable.

The zooplankton community in the YBT dam impoundment is not very diverse with only 27 species. This community presented two proliferation peaks, the first in winter and the second in autumn. While, the summer period is characterized by low zooplanktonic densities. This summer decline

coincides with the proliferation of the chlorophyte *Closterium pronum*. This shows the importance of the quantity of available nutrient resources for the development of zooplankton populations. In general, the zooplankton of the YBT impoundment is dominated by a majority of small Rotifers, which account for a large portion of the total density of the zooplankton community in this impoundment. The abundance of Rotifers in the YBT impoundment may be related to their high nutritional plasticity. They have prioritized the use of phytoplanktonic species of the class Chlorophyceae as frequent preferential resources in stressed ecosystems (Krztoń et al. 2019). The abundance of larger zooplanktonic species such as Copepods and Cladocerans underwent a regression during our study mainly in summer. This summer decline of Copepods, mainly the Calanoid *Neolovenula alluandi*, may be related to unfavorable physicochemical factors and the quality of non-ingestible nutrient resources, as it may also be due to predation pressure and/or intraspecific and interspecific competition for nutrient resources in the water column. These results corroborate with the findings of Mwapu Isumbisho's research (Isumbisho et al. 2006) who have shown that the low abundance of Cladocerans in reservoir lakes is related to environmental conditions such as low water volume and enrichment of the environment in nutrients (phosphorus), which is beneficial to the development of small daphnids. In general, the evolutionary pattern of copepods is comparable to that of Cladocerans. The explanation proposed for Cladocerans also applies to the density fluctuations of both Copepods.

The results of the "Spearman" correlation test of our data showed that conductivity and water level drop were factors that significantly influenced zooplankton development in this reservoir.

CONCLUSION

Our study revealed that the reduction of the water level in the YBT dam reservoir enriches the environment with dissolved ionic and inorganic elements, reducing water transparency and affecting the biodiversity of planktonic communities by increasing density and reducing their specific richness. This intensifies a multitude of problems related to eutrophication. This qualitative degradation of the water is globally the result of an excessive exploitation of this resource and a lack of recharge of the dam because of the drought that the region has experienced during this period.

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